The UC-LLNL Regional Climate System Model

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ABSTRACT

The UC-LLNL Regional Climate System Model has been under development since 1991. This unique system simulates climate from the global scale down to the watershed catchment scale, and consists of data pre- and post-processors, and four model components. The four model components are (1) a mesoscale atmospheric simulation model, (2) a soil-plant-snow model, (3) a watershed hydrology-riverflow model, and (4) a suite of crop response models. The first three model components have been coupled, and the system includes two-way feedbacks between the soil-plant-snow model and the mesoscale atmospheric simulation model. This three-component version of RCSM has been tested, validated, and successfully used for operational quantitative precipitation forecasts and seasonal water resource studies over the southwestern U.S. We are currently implementing and validating the fourth component, the Decision Support System for Agrotechnology Transfer (DSSAT). A description of the UC-LLNL RCSM and some recent results are presented.

INTRODUCTION

Global Climate System Models (GCSMs) have been under development, in part, since the late 1960's, when Atmospheric General Circulation Models (AGCMs) and Oceanic General Circulation Models (OGCMs) were first coupled (Manabe and Bryan 1969). The main focus of these GCSMs was to determine the dynamics and feedbacks within such two component systems. These coupled AGCM-OGCM systems were primarily used to understand and predict global dynamic response due to increasing atmospheric carbon dioxide concentrations (e.g. Washington and Meehl 1989, Manabe et al. 1991) and El Niño Southern Oscillation (ENSO) events (e.g. Barnett et al. 1988).

GCSMs are run at coarse to medium resolution, and consequently produce output data fields that often completely omit regional scale features. Williamson et al. (1995) suggest that finer scale calculations are required to capture the nonlinear processes that force the medium scales. Process-based physics (e.g. clouds, hydrology, vegetation) require a fine-resolution grid for a representative simulation. Fine-resolution global modeling is currently computationally unfeasible, even though rapid advances in high performance computing may make it possible early in the next century. Hence, for present and near future research, regional climate system models (RCSM) nested within GCSM grids together with AGCM ensemble forecasts and observational data appear to be the most cost-effective approach for understanding, validating, and predicting globally forced regional climate.

In recent years, a number of groups have worked toward the formulation of nested mesoscale atmospheric models and RCSMs (e.g. Dickinson et al. 1989, Pielke et al. 1992, Giorgi 1995). Initially, regional climate system modeling focused on the development of a fine resolution regional model with validated atmospheric processes such as precipitation, wind, and temperature fields. As the importance of the interactions between the regional atmosphere and the land surface-hydrologic-ecosystem interface was recognized, coupled regional climate system models began to emerge. RCSMs can provide sophisticated, fine-resolution, and physically-based representations (Dickinson et al. 1991, Pielke et al. 1992, Giorgi et al. 1995, Soong and Kim 1996). However, the land surface models are for the most part surface vegetation atmosphere transport schemes that often lack process-based ecophysiology and lateral hydrological transport (river flow). The next section provides a brief overview of the UC-LLNL Regional Climate System Model (RCSM), followed by a discussion of some recent results and future directions.

MODEL DESCRIPTION

The UC-LLNL Regional Climate System Model has been under development since 1991. It is designed to include complex interactions among the atmosphere, the land surface, and subsurface — including vegetation, energy and water budgets, lateral hydrologic transport, and ecophysiology. Our RCSM runs on several high performance computing platforms. It includes an advanced preprocessor for importing, interpreting, and analyzing atmospheric and land-surface data, a validated and operational mesoscale atmospheric simulation model, a fully coupled multi-layer soil-plant-snow model, a physically based watershed hydrology-riverflow model, and a post-processor for output data analysis, assessment, and visualization (Fig. 1). We are currently importing forest productivity modules (Amthor 1994) and a suite of well validated crop models (Hoogenboom et al. 1995) into this regional climate system model.

The preprocessor contains a flexible input data capability that can readily obtain data from various outside sources. It also includes an Automated Land Analysis System (ALAS, Miller 1996), and a homogeneity decomposition and regrouping tool

(HTEST: Miller 1995). ALAS computes topographic and hydrologic characteristics at each pixel, watershed, and each large-scale cell. It generates a series of data sets which further describe watershed properties (e.g. flow directions, river systems, watershed boundaries, hydrologic-topographic characteristic probability density functions, etc.). The HTEST is a multi-dimensional array decomposition and grouping scheme. It provides an objective and dynamic capability for determining sub-regions of homogeneity within a heterogeneous domain. HTEST may reduce computational time by an order of magnitude, it provides a new approach toward dynamic adaptive gridding, and can be used as an information filter through the adjustment of the threshold criteria.

The Mesoscale Atmospheric Simulation (MAS) model is a limited-area primitive-equation model with 18 atmospheric layers and horizontal resolutions up to 10 km (Soong and Kim 1996). Precipitation is computed as grid-scale and convective. Grid-scale precipitation is based on the bulk cloud physics parameterization of Cho et al. (1989) and includes four classes of hydrometeors (cloud water, cloud ice, rain, and snow). Convective precipitation is based on the cumulus parameterization of Anthes (1977). MAS includes a multi-layer solar radiation scheme, a terrestrial radiative scheme, and a third-order accurate advection scheme. Vertical momentum, heat, and moisture transfer at the surface are computed by the bulk aerodynamic transfer scheme of Deardorff (1978). MAS has shown excellent skill, particularly in heavy precipitation simulations.

The Soil-Plant-Snow model (SPS) is a three layer version of the canopy-atmosphere-plant-soil model developed at Oregon State University (Mahrt and Pan 1984). Prognostic equations predict soil temperature, soil water content, canopy water content, and equivalent snow depth. Snow melt rates and runoff have been incorporated into the hydrology-riverflow model. SPS has been used for seasonal soil-surface energy budget studies (Kim and Eke 1995) and is part of the Program for Intercomparison of Land-surface Process Schemes (PILPS), where it compared very well to observations (Qu et al. 1996).

The watershed hydrology-riverflow model is physically-based, fully-distributed, and is a modified version of TOPMODEL (Beven et al. 1994). TOPMODEL computes the soil water budget, surface and subsurface flow, and the volume of routed river flow in a specified area. It has been improved to include effects of spatial heterogeneity on hydrologic processes (Sivapalan et al. 1990, Wood et al. 1990), and has been applied to many surface hydrological studies including the effects of terrain on streamflow (Beven and Wood. 1983), the effect of climate change on hydrological processes (Wolock and Hornberger 1991), and short-term riverflow forecasting (Miller and Kim 1996). Our version of TOPMODEL has been further modified such that it is driven by atmospheric and land surface simulated variables (precipitation, temperature, winds, radiation, snow melt, and runoff) computed within the RCSM.

The post-processor is equipped with a variety graphical tools that readily provide visualization of all climate fields. Statistical packages and specialized codes provide detailed information on climate variability, averages, deviations, etc. The post-processor is continuously being upgraded and enhanced.

RECENT RESULTS

Our RCSM is able to run simulations with input data spanning from the global scale down to the watershed catchment scale. In this section, we describe two river flow simulations based on new down-scaling techniques.

During the 1994-95 winter season, the fully coupled MAS and SPS models were in continuous operation from November 1994 until May 1995 for a domain that includes California, Nevada and part of their neighboring states. The National Center for Environmental Prediction (formally NMC) ETA model initial data was used to drive the mesoscale simulation from November 1994 to May 1995. Once the simulation was initialized, time-dependent lateral boundary conditions obtained from the twice-daily ETA model initial fields were automatically inputted into the RCSM preprocessor to provide the MAS model with the necessary large-scale forcing conditions. The SPS model was initialized using the November climatology of soil water content obtained from Zobler (1986). Watershed-mean variables were computed by projecting area weight-averaged MAS and SPS model grid-point values onto each watershed. The watershed hydrology-riverflow model was set up for two Northern California headwaters, (1) the Headwater of the Russian River watershed (Hopland Watershed) and the Headwater of the North Fork of the American River (NFAH). The Hopland watershed was calibrated with a 20 year precipitation and river flow history. The NFAH was not calibrated to observations, as they were not available.

During January 1995 (a strong ENSO year), a series of storms from the Pacific Ocean moved over the Southwestern U.S. and caused heavy precipitation with local flooding (Fig. 2 a,b). The simulated river flow at the Hopland gauge station agrees closely with the observed values. During the 64-day period (January to March 1995) shown in Fig. 2 b, the simulated river flow showed better than 50% accuracy when compared to observations. During the high flow periods of early January and March 1995, the numerically predicted river flow agreed with the stream gauge observations with better than 90% accuracy .

The focus of the NFAH was to determine the timing of runoff as a function of snowmelt based on area weight-averaged values of precipitation, snowmelt and other atmospheric variables. The elevation within this catchment varies from 450m to 2450m, where the typical winter time freezing level for this region is between 1000m and 2000m. Fig. 3 shows the MAS model simulated watershed average mean daily freezing level for NFAH. This temperature prognostic is an indicator of snow accumulation. Fig. 4 shows the predicted 6 hour surface rainfall, snowfall, snowmelt, and riverflow. The diurnal melting cycle is visible along with the spring melt and river rise. Accurate predictions of high elevation snowmelt, runoff, and river flow are of great importance to reservoir managers and flood forecasters.

These two numerical simulations, which use large-scale forecasts to force the mesoscale and provide inputs to the

watershed scale, are examples of this new approach to down-scaling. The observational riverflow values act as a validation for this entire calculation. The work to date may be viewed primarily as a proof of the concept of climate and weather variable down-scaling for forecasting water resources and river stage.

FUTURE WORK

Ongoing and future RCSM work involves further model validation, some generalization of processes, code speedup, and application to several geographical locations. In addition to these efforts, we are working on implementing forest and crop productivity models into the RCSM framework. There are a number of comparisons that RCSM model components are a part of, this includes a river flow intercomparison of the Russian River, a mesoscale model intercomparison over the southwestern U.S., and the Program for Intercomparison of Land-surface Parameterization Schemes (PILPS). Code speed up has been focused on the mesoscale atmospheric simulation model. We are currently looking into opportunities for importing the RCSM to the new symmetric parallel computing platforms that are a part of DOE's Advanced Super Computing Initiative. The forest model of Amthor (1994) is being tested at the Oak Ridge National Laboratory site and is expected to be implemented into the RCSM in the near future. At this time, the crop models are run off-line with RCSM produced output data. However, we expect to integrate the validated.Decision Support System for Agrotechnology Transfer (DSSAT) into the RCSM during the next year.

CONCLUSIONS

The UC-LLNL Regional Climate System Model is a subset to our high performance computing global climate research efforts. It includes an advanced preprocessor, a validated and operational mesoscale atmospheric simulation model, a fully coupled multi-layer soil-plant-snow model, a physically based watershed hydrology-riverflow model, and a post-processor. We are importing forest and crop productivity models into this system. RCSM has performed well in predicting regional weather, climate, and river flow. We regard the RCSM as a future tool for regional impact assessment of climatically sensitive regions and are applying this system to the southwest U. S. as part of the University of California - Campus Laboratory Collaboration (CLC) program, and to east Asia as part of NASA's Mission To Planet Earth (MTPE) program.

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REGIONAL CLIMATE SYSTEM MODEL

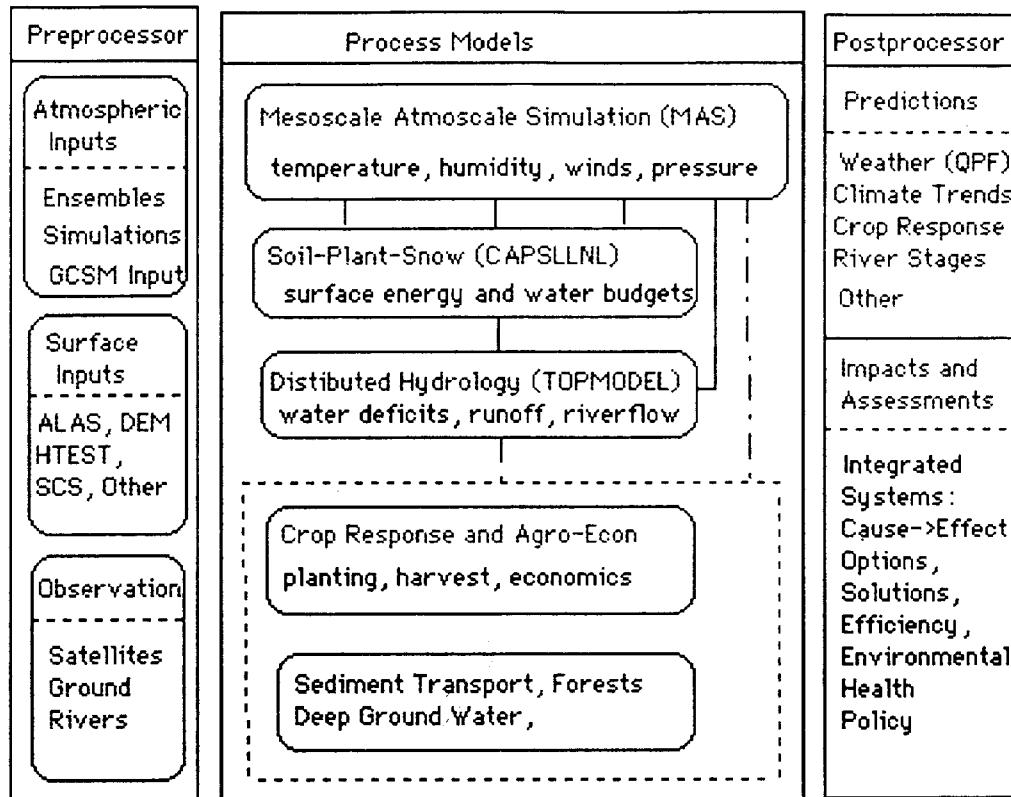| Preprocessor	Process Models	Postprocessor
Atmospheric Inputs - - - - - - - Ensembles Simulations GCSM Input **Surface Inputs** - - - - - - - ALAS, DEM HTEST, SCS, Other **Observation** - - - - - - - Satellites Ground Rivers	Mesoscale Atmoscale Simulation (MAS) temperature, humidity, winds, pressure Soil-Plant-Snow (CAPSLLNL) surface energy and water budgets Distibuted Hydrology (TOPMODEL) water deficits, runoff, riverflow Crop Response and Agro-Econ planting, harvest, economics Sediment Transport, Forests Deep Ground Water,	**Predictions** - - - - - - - Weather (QPF) Climate Trends Crop Response River Stages Other **Impacts and Assessments** - - - - - - - Integrated Systems: Cause->Effect Options, Solutions, Efficiency, Environmental Health Policy

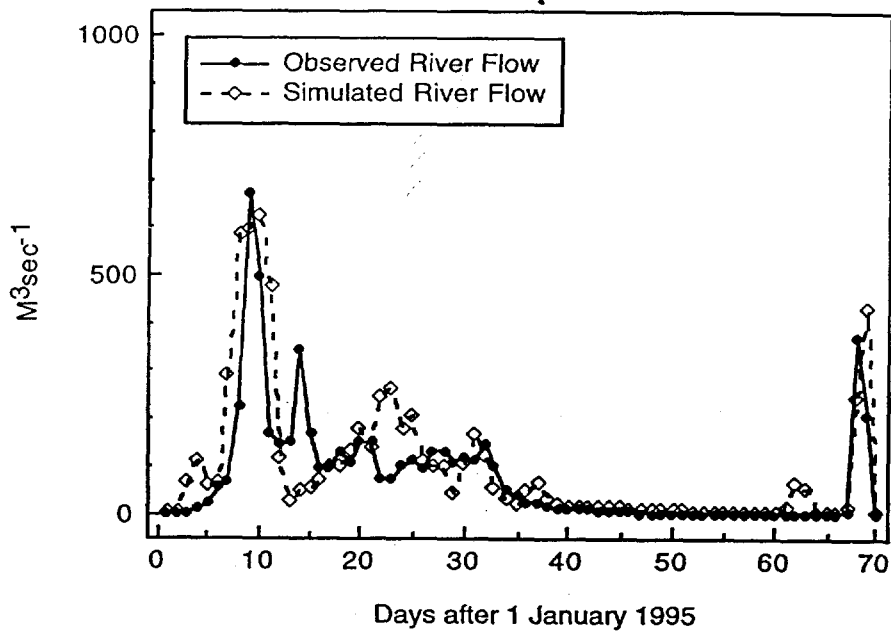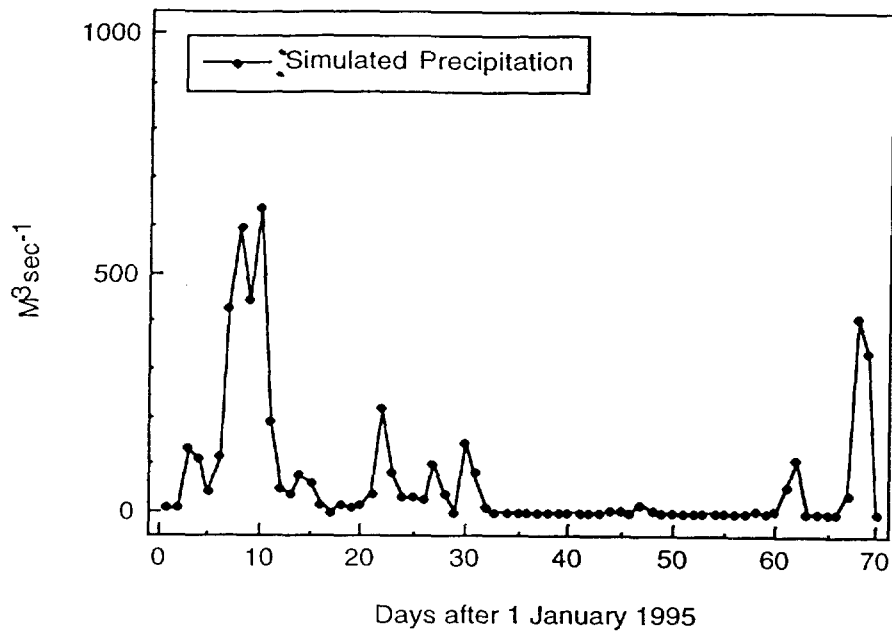Figure 1. The UC-LLNL Regional Climate System Model

Figure 2. A. Numerically predicted precipitation over the Hopland Watershed,
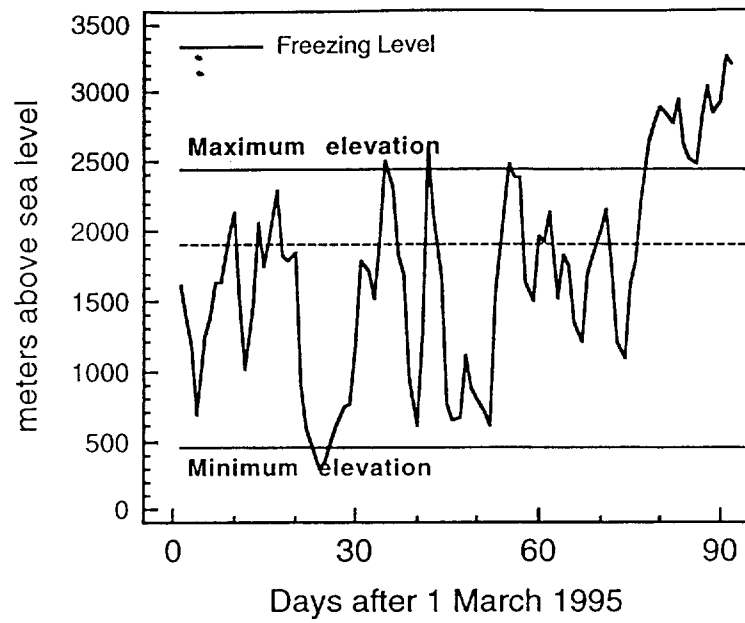B. Observed and numerically predicted river flow at the Hopland gauge station.

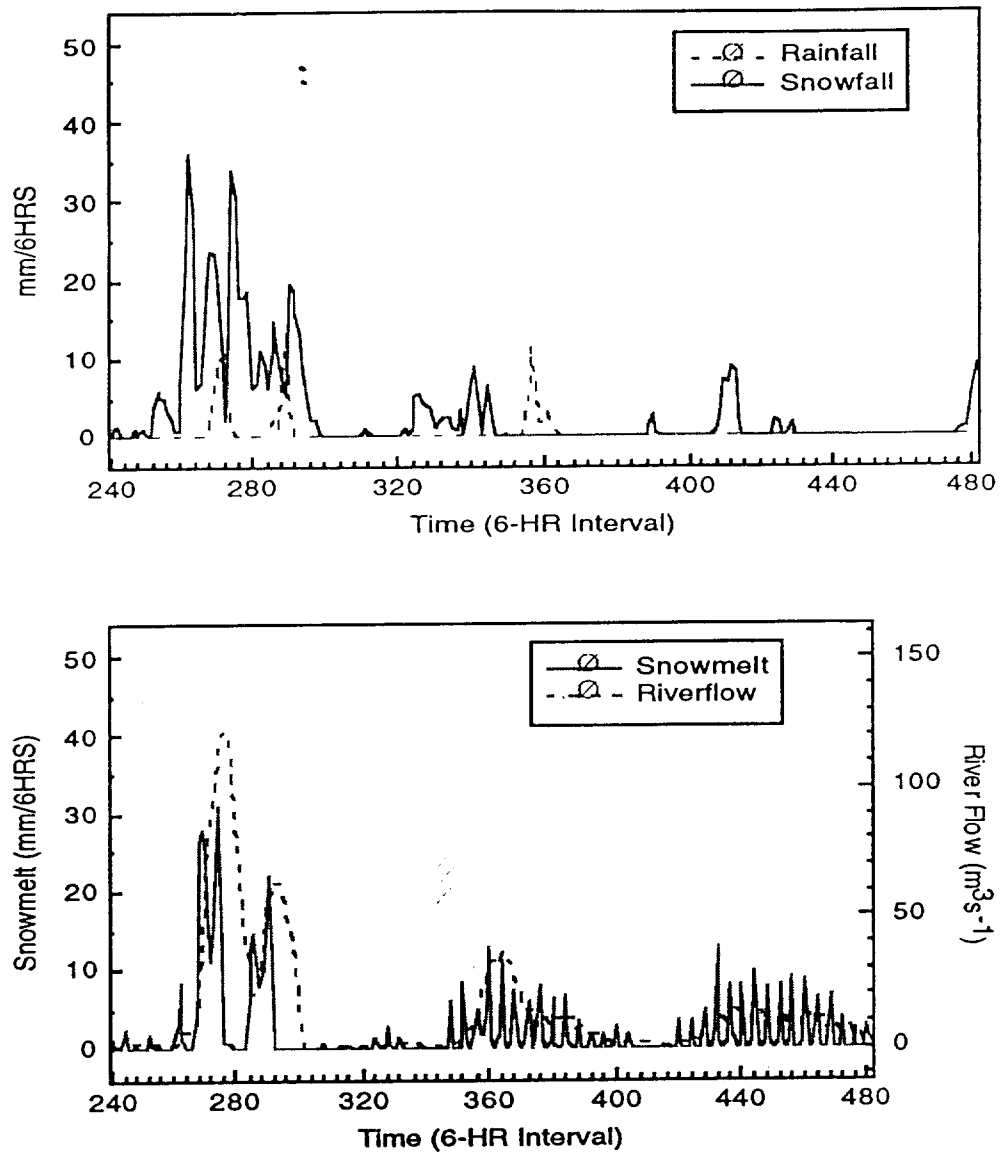Figure 3. The numerically predicted average daily freezing level for the NFAH Watershed.

Figure 4. RCSM predicted 6 hour rainfall, snowfall, snowmelt, and river flow for the NFAH Watershed from November 1994 to May 1995.